ASSESSMENT OF SECONDARY FRAGMENT THREATS
FROM CONVENTIONAL DOD BUILDING CONSTRUCTION

BY

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ABSTRACT

Army installations have to begin to make more
efficient use of property. The default DoD 6055.9
minimum inhabited building separation distances required
for secondary fragments are often excessive and they are
difficult and costly to meet. In order to reduce the
separation distance it is required to determine, using
approved methods, the separation distance providing a
fragment density of less than 1 hazardous fragment per
600 square feet. Until recently a standard approved
method was not available. A procedure was developed by
Southwest Research Institute for the Department of
Energy (DOE) and the Department of Defense Explosive
Safety Board (DDESB). This procedure was approved for
use by DDESB and is described in Technical Paper No. 13
(TP 13), "Prediction of Building Debris for
Quantity-Distance Siting". However, this method is
complex and requires experience in fragment analysis and
the use of three explosive analysis computer programs.
This paper summarizes a study by Huntsville Division,
U.S. Army Corps of Engineers for DDESB on a
simplification of procedures in TP 13 for typical Army
construction types. The procedure is intended for
personnel with limited fragment analyses experience.

BACKGROUND

The Army explosive safety and processing community requires
easy to use, quick, accurate tools to assess safety hazards
resulting from explosions. In the past, Army installations had
ample property and could ensure personnel and public safety by
providing large separation distances between inhabited buildings
and explosive processing and storage facilities. Formerly remote
Army installations are now often surrounded by inhabited private
property. Efficient use of available property is required and
desired while maintaining personnel safety. The recent events in
Henderson, Nevada have illustrated that neglecting safety is
costly in both lives and money. It is therefore necessary that a
more accurate and relative determination of threats to personnel

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safety from accidental explosions be used.

There has been accepted methodology established for determination of the hazards posed by overpressure and primary fragments. There was not a consistently accepted methodology for analyzing the secondary fragment threats resulting from the breakup of the structural elements of facilities in an explosion.

Department of Defense (DoD) 'Ammunition and Explosives Safety Standards', DoD 6055.9-STD, (Reference 1) establishes uniform safety standards applicable to ammunition and explosives. Reference 1 states that "For populous locations ... where military, civilian employees, dependent and/or public personnel are located, the minimum distance (from the explosion source) shall be that distance at which fragments, including debris from structural elements of the facility or process equipment, shall not exceed a hazardous fragment density of one hazardous fragment per 600 square feet." Reference 1 defines a hazardous fragment as one having an impact energy of 58 ft-lb or greater. If this distance is not known, Reference 1 states "For 100 lbs NEW (net equivalent weight) or less of demolition explosives, thin-cased or low fragmentation ammunition items, bulk high explosives, pyrotechnics, and in-process explosives of Class/Division 1.1, the minimum distance ... shall be 670 ft." . Reference 1 further states that "For all types of Class/Division 1.1 in quantities of 101 to 30,000 lbs NEW, the minimum distance shall be 1250 ft ...".

The default minimum inhabited building separation distance for secondary fragments (IBD-F) required by Reference 1 are often overly conservative for structural debris. To avoid using the default IBD-F the hazardous fragment distance corresponding to 1 hazardous fragment per 600 square feet (HFD) must be determined. Historically, explosive safety personnel were given little guidance in determining the HFD. Thus, methods varied substantially. In order to provide consistency in analysis, the Department of Defense Explosive Safety Board (DDESB) issued Technical Paper No.13, 'Prediction of Building Debris for Quantity-Distance Siting', (Reference 2). Reference 2 provides an analytical model for determining the hazardous fragment density resulting from building debris. The model was developed by Southwest Research Institute (SwRI) for the Department of Energy (DOE) Safety Office under funding by DOE and DDESB for some common construction types. The model was refined and verified based upon data from testing by SwRI for DOE.

TECHNICAL PAPER NO.13 ANALYTICAL MODEL

Reference 1 provides a methodology with which to determine the hazardous fragment density resulting from building debris. The method involves the use of the three computer programs in

addition to hand calculations. The computer programs SHOCK and FRANG, developed by the Navy Civil Engineering Laboratory (NCEL), are used, respectively, to determine the explosive shock and gas pressures on the structural elements. The computer code MUDEMIMP, developed by NCEL and refined by SwRI to reflect test data, is then used to estimate the hazardous fragment density. MUDEMIMP requires as input the average mass based upon construction type, average velocity calculated using the loadings from SHOCK and FRANG, and initial trajectory of the building debris along with appropriate statistical distribution parameters. Through use of a monte-carlo randomization computer routine and statistics, MUDEMIMP determines trajectory distances for up to 5000 individual fragment weights, velocities, and initial trajectories and predicts a conservative estimate of the debris density.

The fragments are always assumed to eject normal to the surface of the structural element being considered with a standard deviation of between 1.3 and 10 degrees. The horizontal fragment dispersion used by MUDEMIMP is as shown in Figure 1 (from Reference 2). GRIDL is the effective destroyed wall width. MUDEMIMP bases its determination of hazardous fragment densities on an effective destroyed weight of structural element. The number and weight of fragments considered are also based on this effective destroyed weight. Only debris with an impact energy of greater than 58 ft-lbs are considered. MUDEMIMP predicts roll based upon the fragment impact velocity for the fragments with impact angles under 50 degrees. Fragments that have impact angles over 50 degrees are not assumed to roll.

MUDEMIMP produces two output files. 'MIMP.OUT' provides all pertinent information on each of up to 5000 fragment trajectory simulations. 'MIMP.HIS' gives the maximum hazardous fragment distance (MFD) and the critical distance for cumulative risk (HFD). Mimp.his also provides hazardous fragment density (number of fragments per 600 sf) at successive distances from the surface.

This model, while extremely valuable to explosive safety specialists, requires experience in fragment analysis and in the use of the three computer programs. Safety personnel who do not regularly use this analytical model will find it time consuming, frustrating and costly to use. It is therefore desirable to have a simplified procedure for use on common Army building types.

Army Building Debris Study

The purpose of the study by the Corps of Engineers, Huntsville Division, is to provide a simple tool based upon Reference 2 to estimate the hazardous fragment density resulting from structural debris for typical U.S. Army building
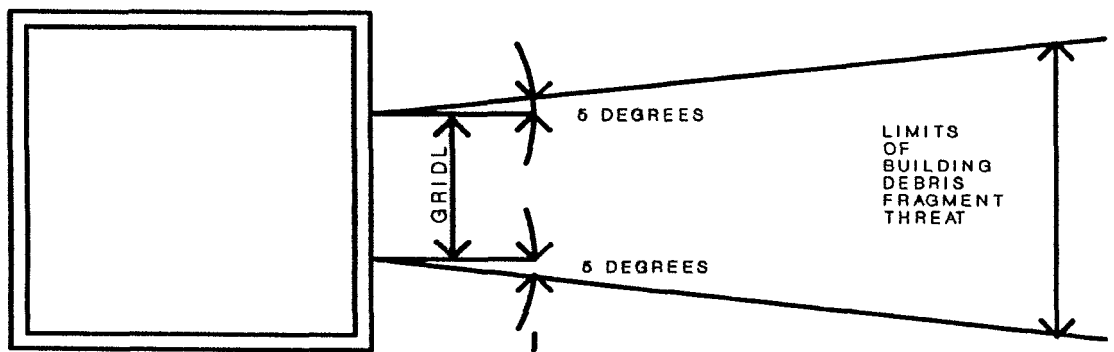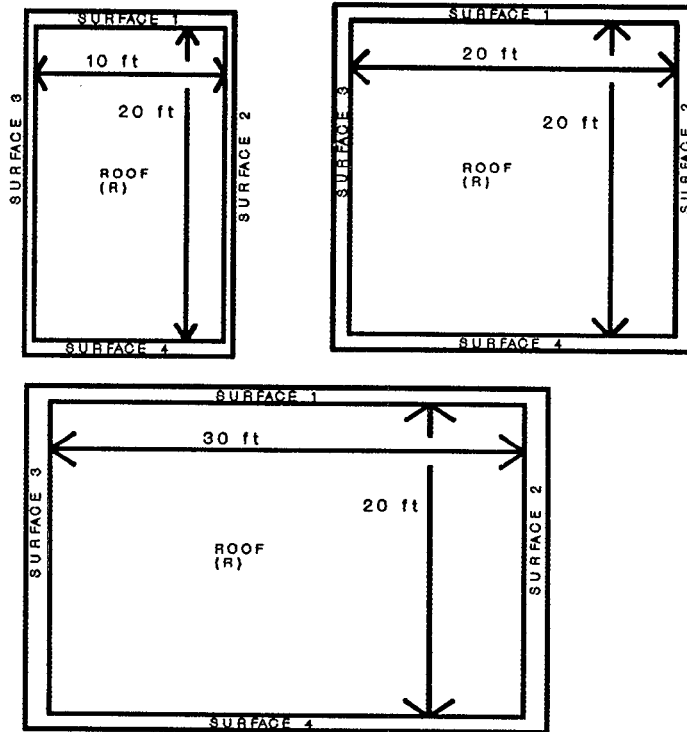
BUILDING DEBRIS LIMITS

FIGURE 1 - MUDEMIMP BUILDING DEBRIS LIMITS

CONSTRUCTION TYPE

ABRV.	DESCRIPTION	FOR USE ON SURFACES
CSF	CORRUGATEED STEEL PANELS SUPPORTED ON STEEL CHANNELS WITH 1" INSULATION AND 5 PLY FELT AND GRAVEL.	ROOF
CSF	CORRUGATED STEEL PANELS SUPPORTED ON STEEL CHANNELS	1 AND 2
RC	12" THICK REINFORCED CONCRETE WITH #4 BARS @ 12" SPACING IN EACH DIRECTION ON EACH FACE	1,2,3, AND 4
CMU	8" STANDARD CONCRETE MASONRY UNIT	1,2,3, AND 4
SB	8"x12" STRUCTURAL BRICK	1,2,3, AND 4

FIGURE 2 - STUDY PARAMETERS

construction types.   The main objective is to provide a method which would require little or no knowledge of the procedures described in reference 2.   Therefore, a graphical procedure is being developed based upon the use of a set of graphs depicting hazardous fragment density versus distance for typical construction materials, bay sizes, and venting conditions.   The use of the procedure will be described later in this paper.

The study parameters including bay sizes, construction materials, and venting surfaces are shown in Figure 2.   Three bay sizes with surfaces 1 and 2 as possible vent surfaces and the roof always as a covered venting surface are considered.   The four construction materials considered are as follows:

1   20 gage corrugated metal deck frangible surface
        (with 1" rigid insulation and 5 ply felt and
        gravel on roof)
        supported on structural steel channels (CSF)

2   12" thick concrete reinforced with #4 bars at 12"
        spacing each way on each face (RC)

3   unreinforced 8" standard concrete masonry unit
        (CMU)

4   8"x12" unreinforced structural brick (SB)

The three bay dimensions are as follows:

1   20' long by 10' wide by 20' high

2   20' long by 20' wide by 20' high

3   20' long by 30' wide by 20' high

Fragment analyses based upon Reference 2 will be performed for each bay size, venting condition, and material type for net equivalent explosive weights of 25, 50, and 100 pounds.

The product provided from this study will be a set of 62 graphs of the expected hazardous debris density versus distance from the structural element, the maximum hazardous fragment range (MFD), the maximum critical distance for cumulative risk (HFD), and the zero hazardous fragment density distance (ZFD).   A sample graph as will be presented in the final study report is shown in Figure 3.
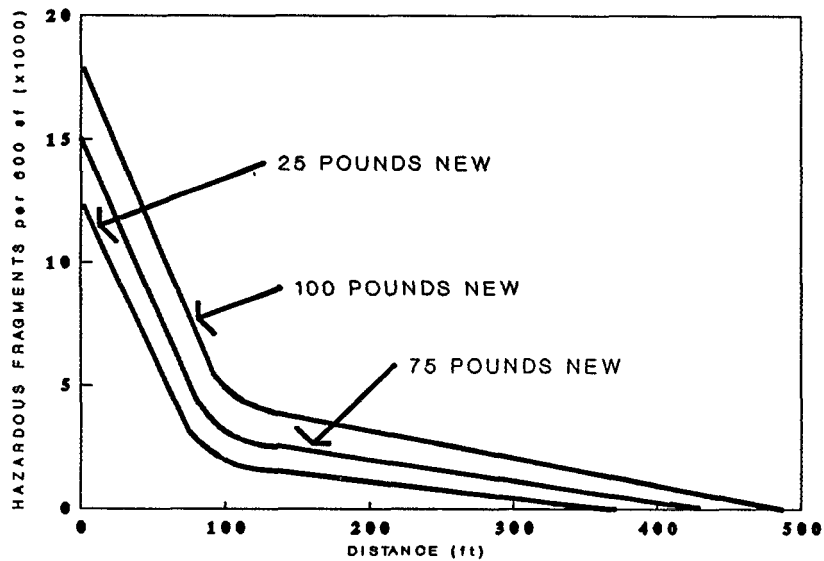
EXAMPLE

As an example to illustrate how the information provided within the study can be used, a situation as shown in Figure 4 is

ARMY BUILDING DEBRIS STUDY

GRAPH 34

FOR EXAMPLE ONLY

25 POUNDS NEW
MAXIMUM PREDICTED DISTANCE = 360 ft
MAXIMUM PREDICTED CRITICAL DITANCE FOR CUMULATIVE RISK (HFD) = 345 ft
ZERO HAZARDOUS FRAGMENT DENSITY DISTANCE = 370 ft

50 POUNDS NEW
MAXIMUM PREDICTED DISTANCE = 430 ft
MAXIMUM PREDICTED CRITICAL DITANCE FOR CUMULATIVE RISK (HFD) = 415 ft
ZERO HAZARDOUS FRAGMENT DENSITY DISTANCE = 440 ft

100 POUNDS NEW
MAXIMUM PREDICTED DISTANCE = 480 ft
MAXIMUM PREDICTED CRITICAL DITANCE FOR CUMULATIVE RISK (HFD) = 465 ft
ZERO HAZARDOUS FRAGMENT DENSITY DISTANCE = 490 ft

FIGURE 3 - SAMPLE STUDY GRAPH (NOT FOR USE - EXAMPLE)

EXPLOSIVE PROCESSING PLANT

20 ft

SB

CSF 25 lbs NEW
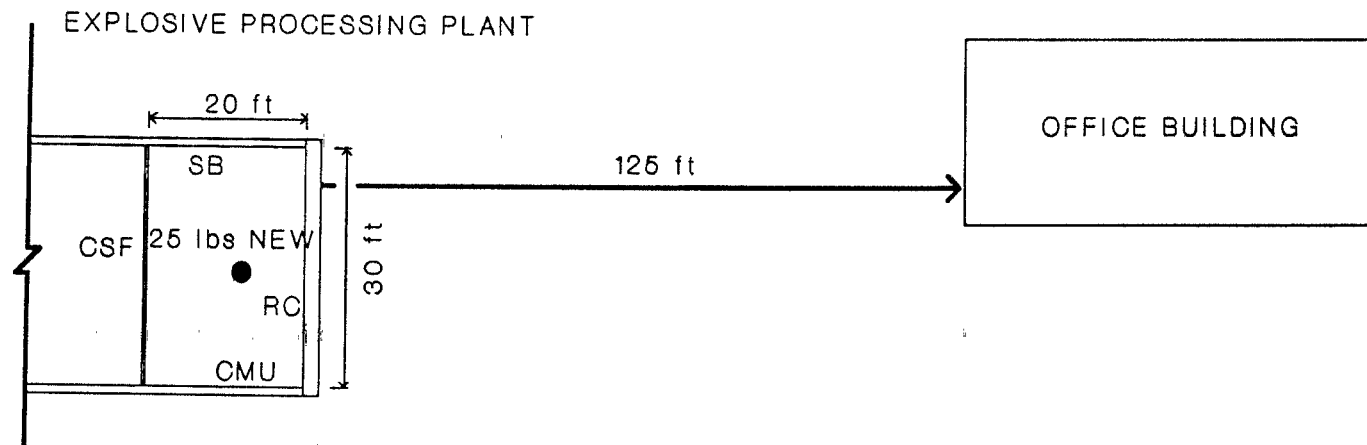●
RC

CMU

30 ft

125 ft

OFFICE BUILDING

504

FIGURE 4 - EXAMPLE CONFIGURATION

considered.   There is a explosive processing plant with an end
bay having a 12" concrete thick back wall, masonry side walls and
frangible metal deck front wall and roof.   The end bay has
interior dimensions of 30 feet wide by 20 feet long by 20 feet
high.   There is 25 pounds net equivalent weight of explosive in
the end bay.   An office building is located 125 feet from plant.
The default IBD-F required by Reference 1 is 670 feet.   The
hazard to personnel in the office building resulting from an
accidental explosion in the plant's end bay must be determined.

The first step is to determine which surfaces contribute to
the secondary fragmentation hazard at the office building.
Figure 5 shows the limits of fragment scatter for each surface.
It can be seen that only building debris from the concrete back
wall and the metal roof deck need be considered for determining
the hazardous fragment density at the office building.   From
figure 2, it is noted that the back concrete wall of the end bay
corresponds to surface 4.

The next step is to select the graphs which will be used in
determining the aggregate fragment hazard.   The graph selection
chart (Figure 6) is used to determine which graphs are to be used
for the situation in question.   Therefore, graph 27 (Figure 7)
for the back wall (surface 4) and graph 29 (Figure 8) for the
roof (surface R) are selected for venting through surfaces 1 and
roof and a bay size of 20 ft by 30 ft by 20 ft.

With the appropriate graphs selected, the values of MFD,
HFD, and ZFD should be looked at for both surfaces.   If the
siting distance is less than either of the two surface's HFD
values, the siting does not meet the requirements of Reference 1
since the hazardous fragment density will exceed 1 fragment per
600 square feet.   Figure 8 states that the MFD for the roof
fragments is 144.2 feet, the HFD is 57.96 feet, and the ZFD is
161 feet.   From Figure 7 for the back wall, the MFD is 124.94
feet, the HFD is 119.30 feet, and the ZFD is 128 feet.   For this
example, the siting distance of 125 feet exceeds the HFD values
for both back wall and the roof.   The hazardous fragment density
for each surface must be determined.   The hazardous fragment
density can be determined in two ways.   First, a direct
interpolation between the HFD and ZFD (Equation 1) for a distance
of 125 feet can be used.

$$1 - ((1 /(ZFD - HFD)) \times (125 - HFD)) \qquad \text{EQUATION 1}$$

Equation 1 can produce an overly conservative number if the
difference between the HFD and ZFD is large (more than a 30%
difference).   Second, the values can be read off of the graph if
the level of accuracy can be assured.   In most cases the concrete
or masonry wall element hazardous fragment density is determined
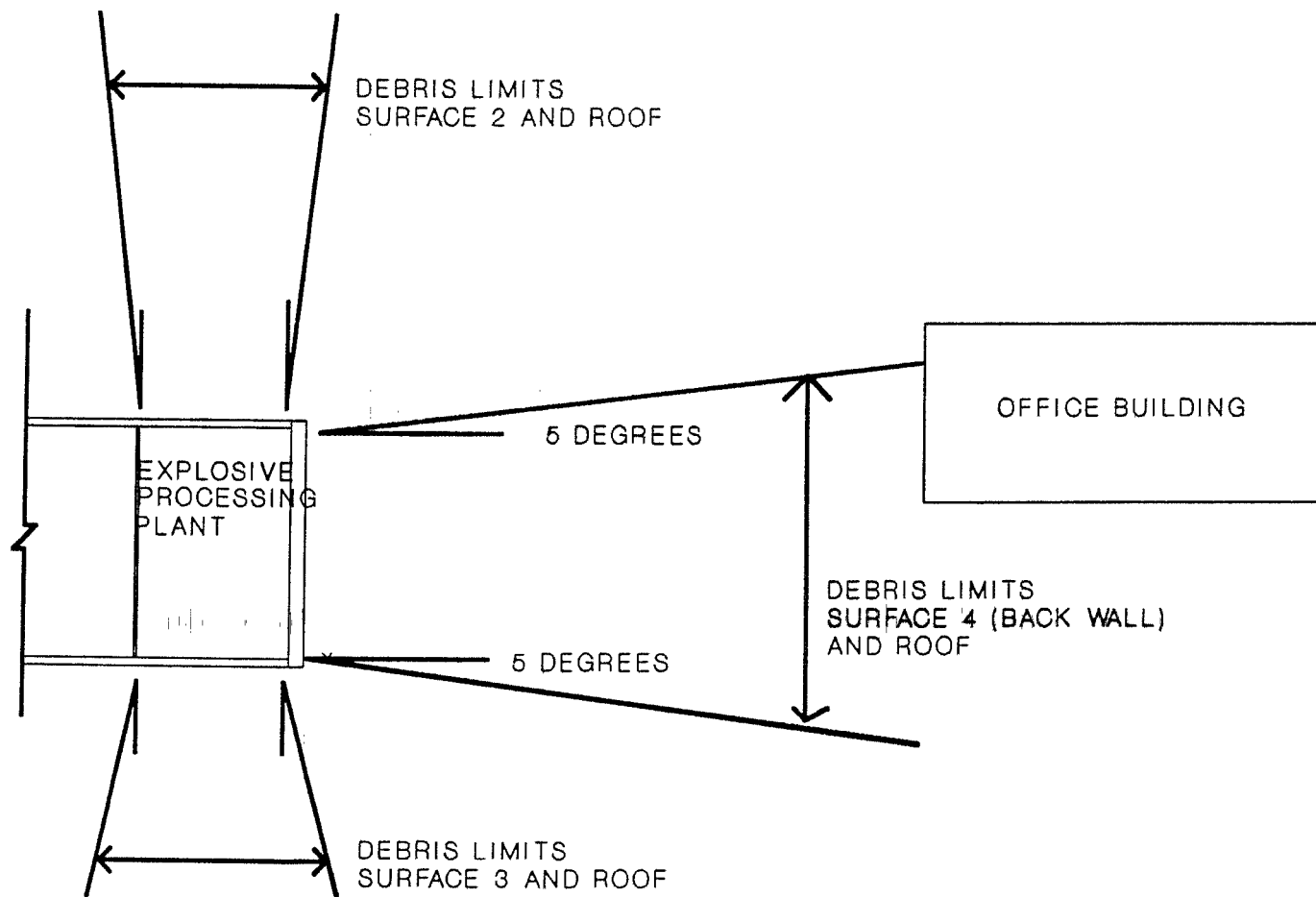by the interpolation method and the hazardous fragment density

DEBRIS LIMITS
SURFACE 2 AND ROOF

OFFICE BUILDING

5 DEGREES

EXPLOSIVE
PROCESSING
PLANT

DEBRIS LIMITS
SURFACE 4 (BACK WALL)
AND ROOF

5 DEGREES

DEBRIS LIMITS
SURFACE 3 AND ROOF

FIGURE 5 - EXAMPLE DEBRIS LIMITS

ARMY BUILDING DEBRIS GRAPHS
SELECTION CHART

VENT SURFACE(S)	BAY SIZE L x W x H	SURFACE 1 CONSTRUCTION CSF	RC	CMU	SB	SURFACE 2 CONSTRUCTION CSF	RC	CMU	SB	SURFACE 3 CONSTRUCTION CSF	RC	CMU	SB	SURFACE 4 CONSTRUCTION CSF	RC	CMU	SB	R CSF
R	20'x10'x20'		1	9	14		2	10	15		2	10	15		1	9	14	3
R	20'x20'x20'		4	11	16		4	11	16		4	11	16		4	11	16	5
R	20'x30'x20'		6	12	17		7	13	18		7	13	18		6	12	17	8
R,1	20'x10'x20'	19					21	31	36		21	31	36		20	30	35	22
R,1	20'x20'x20'	23					24	32	37		24	32	37		24	32	37	25
R,1	20'x30'x20'	26					28	34	39		28	34	39		27	33	38	29
R,1,2	20'x10'x20'	40				42					43	54	59		41	53	58	44
R,1,2	20'x20'x20'	45				45					46	55	60		46	55	60	47
R,1,2	20'x30'x20'	48				48					51	57	62		49	56	61	52

FIGURE 6 - GRAPH SELECTION CHART

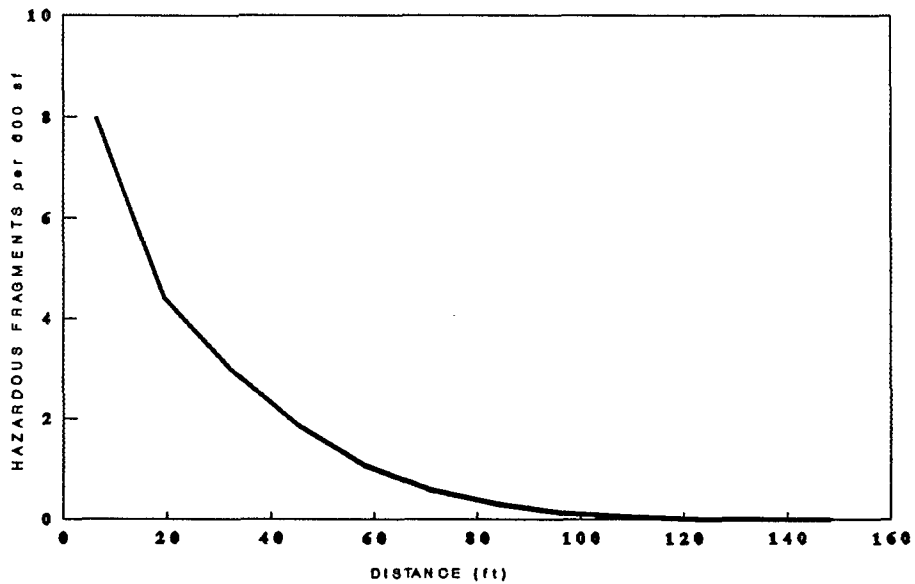ARMY BUILDING DEBRIS STUDY
GRAPH 27 - 25 lbs NEW
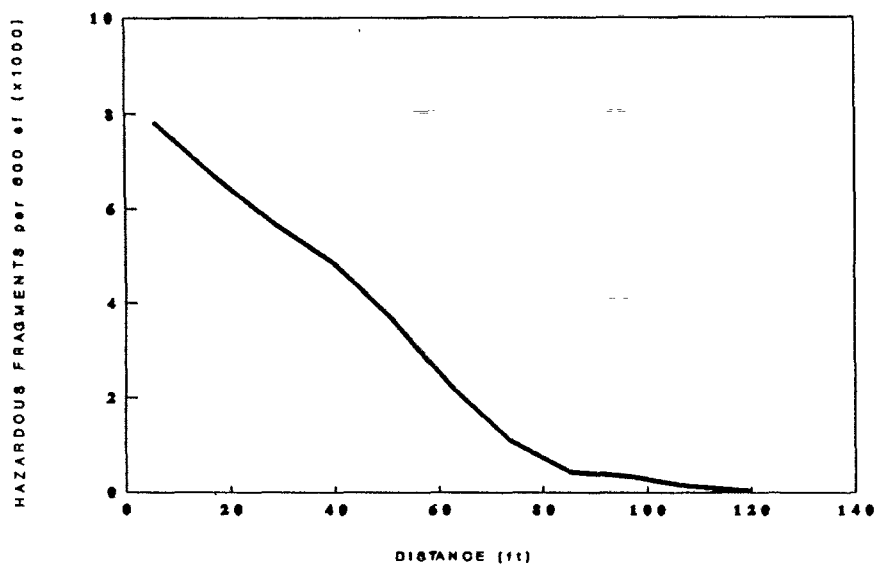
MAXIMUM PREDICTED DISTANCE (MFD) - 124.94 ft
MAXIMUM PREDICTED CRITICAL DISTANCE FOR CUMULATIVE RISK (HFD) - 119.30 ft
ZERO HAZARDOUS FRAGMENT DENSITY DISTANCE (ZFD) - 128 ft

FIGURE 7 - FRAGMENT DENSITY GRAPH FOR BACK WALL

ARMY BUILDING DEBRIS STUDY

GRAPH 29 - 25 lbs NEW

MAXIMUM PREDICTED DISTANCE (MFD) = 144.2 ft
MAXIMUM PREDICTED CRITICAL DISTANCE FOR CUMULATIVE RISK (HFD) = 57.96 ft
ZERO HAZARDOUS FRAGMENT DENSITY DISTANCE (ZFD) = 161 ft

FIGURE 8 - FRAGMENT DENSITY GRAPH FOR ROOF

for the frangible metal decking surfaces are read directly off of the graph. Using Equation 1 for the wall a value is .35 hazardous fragments per 600 square feet is determined. Since the ZFD is much larger than the HFD, a direct interpolation between the two values would be unacceptable for the roof. Reading the graph on Figure 8 for a distance of 125 feet the hazardous fragment density for the roof is approximately .015 hazardous fragments per 600 square feet.

The aggregate (added) hazardous fragment density for the wall and the roof fragments is approximately .365 hazardous fragments per 600 square feet. The required IBD-F based upon 1 hazardous fragment per 600 square feet would be approximately 120 feet.

Reference 1 requires an inhabited building separation distance for overpressure (IBD-P) of K40 ($40W^{1/3}$). For 25 pounds NEW this is equal to 117 feet. As previously stated, the default IBD-F between the explosive processing plant and the office building is 670 feet. However, since the hazardous fragment density at 125 feet from the process facility is under 1 hazardous fragment per 600 square feet, and IBD-P is less than 125 feet, the siting meets the requirements of Reference 1. Other factors that must be considered before final safety approval include hazards resulting from any primary fragments.

CONCLUSION

The study of Army building debris for DDESB is at approximately 60% stage of completion with a completion date of 30 September 1992. This study will provide a guide for determining the hazardous fragment density resulting from building debris of typical Army construction. The study will be usable by personnel with limited fragmentation analysis experience. As shown in the example, the required inhabited building separation distance (IBD-F) was reduced from 670 feet to approximately 120 feet. The use of the procedure developed in the study will enable efficient use of property by reducing the required separation distance for secondary fragments from the default Reference 1 values while maintaining personnel safety.